The Institute of Physics

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The Bulletin is published by The Institute of Physics for circulation to its members ; copies should not be placed in libraries.

Notices to Members

Printing Dispute

The dispute in the printing industry is causing serious delay in most branches of the industry other than the London newspapers. Although the Institute's Journals and the *Bulletin* have so far been published at about the usual dates there may be considerable delay with later issues if the dispute is not settled soon. In order to avoid this as much as possible, the extent of the publications may be temporarily reduced.

The American Institute of Physics Silver Jubilee

The American Institute of Physics celebrated its Silver Jubilee from January 30 to February 3, 1956. On the evening of February 1 a banquet was held at the Hotel New Yorker, New York City, and the following telegram was sent on behalf of British physicists :—" The (British) Institute of Physics sends heartiest congratulations on your Silver Jubilee and best wishes for the continued progress of your Institute and success to your important publications work. Please convey cordial greetings to our many friends assembled for celebrations. For and on behalf of the Board of the Institute, John D. Cockcroft." A reply was received as follows :—" Dear Sir John, On behalf of the American Institute of Physics and its many adherents I would like to thank you for the warm telegram which you sent on behalf of the British Institute on the occasion of the 25th anniversary of the American Institute of Physics. I had the pleasure of

reading your telegram at our ceremonial banquet. It received a warm response from all present, many of whom are your good personal friends. Yours sincerely, Frederick Seitz."

X-Ray Analysis Group Equipment Sub-Committee

The Equipment Sub-Committee of the X-ray Analysis Group of the Institute has recently sponsored a survey of Electronic Counter Circuitry for use with Counter Diffractometers. A memorandum on the subject, edited by Dr. H. F. Kay has been circulated to members of the Group, but other members of the Institute who are interested may also obtain copies (free of charge) from the Secretary of the Institute.

Graduateship Examination Fees

The Board has decided to increase the fees payable by candidates for the Graduateship examination, with effect from the 1957 examination. The fee for a candidate taking the full examination will be increased from six to eight guineas, and the fees for those having partial exemption will also be increased by one-third.

The Physical Society Exhibition

The Physical Society's 40th annual exhibition of instruments and apparatus will be held in the Halls of the Royal Horticultural Society, Westminster, London, S.W.1 from May 14 to 17, 1956 (inclusive).

Members of the Institute of Physics who are not members of the Physical Society may obtain tickets for the exhibition, available for any one day, on application to the Secretary of the Institute.

Symposium on X-ray Microscopy and Microradiography

A symposium, sponsored by the International Union of Pure and Applied Physics, will be held in the Cavendish Laboratory, Cambridge, from August 16–21 next. Its scope will include all microscopic methods which employ X-rays, and sessions are planned on the reflexion, contact and projection methods. Sessions will also be devoted to applications in biology, medicine, metallurgy and other fields, including industrial applications.

Further details may be obtained from Dr. W. C. Nixon, Cavendish Laboratory, Cambridge.

List of Publications

A new list of Institute publications is now available and may be obtained on application to the Secretary of the Institute.

Vol. 7, March, 1956

Genetics and Radiation*

By CHARLOTTE AUERBACH, D.Sc.

(*Department of Animal Genetics, University of Edinburgh*)

IONIZING RADIATIONS affect chemical substances, in particular organic molecules. If the effects are on molecules of the genetic material, inherited changes are produced. Before we consider these effects we have to know something about the genetic material. In all higher organisms it is organized into microscopically visible structures, called chromosomes. These are present in the nucleus of every cell and become visible when the cell divides. Numbers and shapes of chromosomes are a fixed property of a given species, e.g. human cells contain 48 chromosomes, maize cells 20, mouse cells 40 and so on. In a sexually produced organism the chromosomes consist of two sets, one of which is derived from the father, the other from the mother. Thus, the 48 human chromosomes consist of two sets of 24, and—with one exception which is not relevant here—every chromosome in the maternal set has a partner chromosome of equal length and shape in the maternal set. This explains why on the average the two parents contribute about equally to the inheritance of the child.

The most remarkable property of the chromosomes is their capacity for replication. In between any two cell divisions, an exact replica of each chromosome is laid down close to the original ; when division takes place, original and copy separate and go into different cells, with the result that all cells which arise by division from the same ancestral cell contain the same genetic material. Exceptions are the divisions at which the reproductive cells, spermatozoa and egg cells, are formed. At this stage partner chromosomes pair, and the two members of a pair go into different cells, so that the mature reproductive cells contain only one set of chromosomes. In man, for example, the 48 chromosomes form 24 pairs, and spermatozoa and egg cell contain one member of each pair.

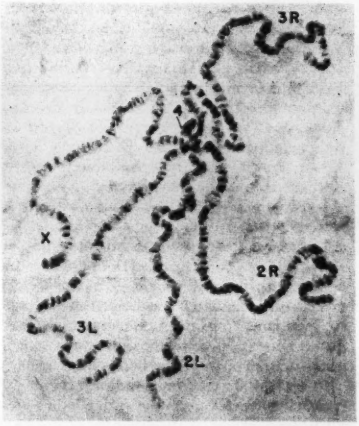

FIG. 1. *Giant chromosomes in the salivary gland cells of* Drosophila *larvae.*

Something of the structure of the chromosomes can be seen in certain favourable cells. Fig. 1 shows giant chromosomes from the salivary gland cells of the fly *Drosophila.* These chromosomes are quite exceptionally large, and they show patterns of cross-striations, which are characteristic for each chromosome. These patterns have been

* A lecture given to the Scottish Branch of the Institute on November 14 and 25 and December 7, 1955.

mapped by cytologists, and an expert can tell when even one band is missing or when the pattern has been changed in some other way.

The discovery of these giant chromosomes was made at a time when breeding experiments had already established that the genetic material consists of discrete units, called genes, which are arranged linearly along the chromosomes. Each gene is concerned with some particular developmental process or processes, affecting, e.g., skin colour, or growth rate, or disease resistance, and it is transmitted as a unit from parents to children. Genes in corresponding spots on corresponding chromosomes govern the same process. Thus, genes as well as chromosomes exist in duplicate in a sexually produced individual. When the giant salivary chromosomes were discovered, it was an obvious step to correlate the visible pattern of cross-striations with the inferred pattern of the genes in *Drosophila*. The attempt was fully successful. Genetically inferred changes in the pattern of genes were found to be reflected in changes in the visible pattern of cross-bands, and when the visible pattern lacks one or more bands, certain genes have ceased to function—the same genes whenever the same bands are missing. This correlation confirms the linear arrangement of genes, although the visible bands are much too large to be the genes themselves.

The chemical nature of the genetic material is still a much debated topic. Chromosomes consist of two main components, protein and desoxyribonucleic acid. Until quite recently, it was taken for granted that the actual carrier of genetical specificity must be the protein component because it did not seem possible that a comparatively simple and regular structure like nucleic acid should be capable of forming the millions of highly specific genes which occur in nature. Nowadays, there has been an accumulation of evidence which points towards nucleic acid as the carrier of genetical specificity. Crick and Watson have derived a double-helix structure for desoxyribonucleic acid from crystallographic studies, and it is believed that the "information" which the genes transmit from generation to generation is carried by the arrangement of the nucleotides along the two chains. For very simple kinds of genetic material, like that found in viruses, this model has proved successful ; how far and with what modifications it can be applied to an interpretation of chromosome structure in higher organisms remains to be decided by further work.

Changes in the genetic material may be of two kinds : changes in the configuration or composition of the gene molecules, and changes in the linear pattern of the genes on the chromosomes. The former are called gene mutations, the latter chromosome re-arrangements. The distinction between these two classes is not absolute. In practice, very small chromosome re-arrangements cannot be distinguished from changes in individual genes. If the specificity of the genes should in fact reside in the linear pattern of nucleotides, it may even in theory be difficult or impossible to draw a line between re-arrangements on this intramolecular scale and larger ones by which groups of nucleotides are transported into new positions. This ambiguity concerns, however, only the very small re-arrangements. For practical purposes, it is convenient to pool these with the gene mutations into one class, and contrast this with the class of large, easily detectable re-arrangements. We shall see that also in X-ray experiments these two classes can be distinguished.

Mutations and re-arrangements arise in nature, the latter very rarely, the former at measurable rates. In different organisms and for different genes the so-called "spontaneous" mutation rates vary from about 10^{-5} to 10^{-8} ; i.e. a particular mutation is found on the average once in 100,000 reproductive cells, or once in 1 million, etc. In man, mutation rates have been estimated for a few heriditary abnormalities ; some were unusually high, about 1 mutation in 50,000 cells ; but it is likely that the average spontaneous mutation rate of human genes is not more than 10^{-6}. This seems to make mutation an exceedingly rare event. So it is, as long as individual genes are considered. But a set of 24 human chromosomes contains probably 10,000 genes or more, and if we

assume an average mutation rate of 10^{-5}, it follows that one out of every 10 human egg cells or spermatozoa carries a newly arisen mutation of one of the genes. Since two reproductive cells go into the making of a new individual, this would result in one out of five newborn children carrying a new mutation ; probably this is still an underestimate.

Once a gene has mutated it is the mutated form which is replicated. There is no recovery from mutation except by the exceedingly rare chance of a second mutation which happens to restore the original gene. The same applies to changes in chromosome pattern which, once arisen, are transmitted indefinitely. The only way in which a new mutated gene or chromosome re-arrangement can be lost is by the death of individuals carrying it or their failure to reproduce.

The causes of mutation have been and still are a matter for speculation. The discovery about 20 years ago that X-rays can produce mutations and chromosome rearrangements in numbers far exceeding those which occur in nature gave a tremendous impetus to mutation work. Physicists—first Crowther in Britain, then Delbrück and Zimmer in Germany—became interested in the subject and developed the so-called target theory of mutation, which for many years dominated mutation research. It is based on quantitative studies of the relationship between X-ray dose and genetical effect. Most of this work was done on *Drosophila*, and I have to digress for a moment in order to explain what types of genetical effect were studied.

When a gene mutates, its effect on development is changed. It still influences the same developmental process as the original gene, but it does so in a different way : mutation of a gene for skin colour may result in darker or lighter colour, mutation of a gene for growth rate in taller or shorter stature. In *Drosophila*, the effects of mutations may show in all parts of the body : eye colour, size and shape of wings, body colour and so on may be changed. It is possible to relate the frequency with which such mutations occur to the kind of X-ray treatment given. This method has, however, several shortcomings. One of them is the fact that mutations with clearly visible effect are very rare, even after irradiation. The other is the large personal error which is unavoidable in this type of work. Muller, who discovered the mutagenic action of X-rays, had already paved the way for the exploitation of his discovery by devising methods for reliable quantitative mutation work. He introduced the use of lethal mutations, that is mutations to genes which disturb development to such a degree that the affected individuals die at some early stage. For a reason to which I shall come back later, lethal mutations are many times more frequent than visible ones, so that statistically significant results can be obtained with manageable numbers of cultures. In addition, Muller developed special techniques for the detection of lethal mutations. Particularly easy is the detection of sex-linked lethals, that is lethal genes which kill preferentially males. In the classical ClB method, a sex-linked lethal gene which arises by mutation in a male reproductive cell is detected as a family of grandchildren which consists entirely of females ; this method leaves little room for personal error. Most of the experiments on which the target theory is based were carried out with the ClB

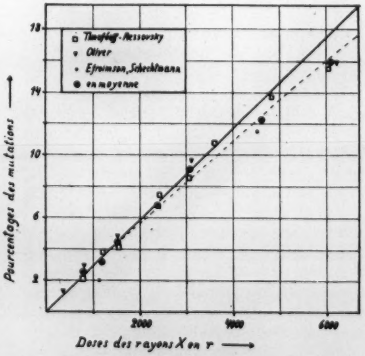

FIG. 2. *The direct proportionality between X-ray dose in r-units and percentage of sex-linked lethals in* Drosophila.

method. The main results are shown in the following graphs.

Fig. 2 shows the relationship between X-ray dose and frequencies of sex-linked lethals. The dose is measured in r-units, i.e. in numbers of ionizations per unit volume, and the effect in percentage of sex-linked lethals. In all experiments this percentage increased linearly with dose. Fig. 3 shows the same dose-dependance for the much rarer visible mutations. This, then, was the

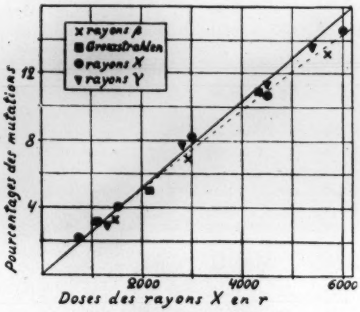

FIG. 3. *The direct proportionality between X-ray dose and percentage of visible mutations in* Drosophila.

first important finding : a linear relationship between dose, as measured in r-units, and frequency of mutations. The second important result is illustrated in Fig. 4. It presents experiments in which treatment producing 10% sex-linked lethals was given at different intensities, either as continuous irradiation spread over various periods of time, or in separate instalments. In all experiments the required dose was in the neighbourhood of 3500 r, independent of whether this was given in ½ hour or in up to 500 hours. Thus, the induced mutation rate depends only on the number of ionizations which are produced in the cell, not on the way in which these ionizations are spread in time. The third basic finding is illustrated in Fig. 5. It shows that, within wide limits, mutation frequency is independent of wave length.

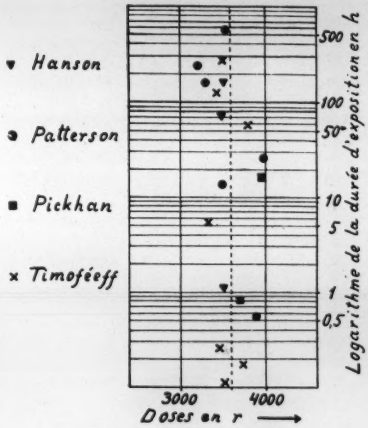

FIG. 4. *The production of 10% sex-linked lethals by various kinds of X-ray treatment (short intensive treatment, fractionated treatment, long treatment at low intensity).*

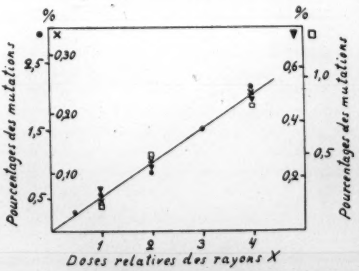

FIG. 5. *The production of sex-linked lethals in* Drosophila *by radiation of different wave-lengths.*

From these findings the conclusion was drawn that a mutation is the result of a single ionization, or perhaps of a cluster of closely neighbouring ionizations. This conclusion is still valid. But the original target theory went farther and assumed that for a mutation to occur the ionization must take place within the gene, and that every ionization which

occurs in a gene produces a mutation. On these assumptions the gene may be considered as a target to be " hit " by a random bombardment with ionized particles, and the size of the gene can be calculated from the number of ionizations within the cell nucleus and the number of mutations which they produce. When this method was applied to inactivation of viruses and enzymes by X-rays it gave estimates of volume which agreed well with the volumes as determined by more direct methods. For *Drosophila* genes, no such direct volume measurements are possible. Some estimates were, however, derived from genetical data, and these were several orders of size larger than the calculated target volume. To save the target theory one had to assume that the target represented a sensitive region within the gene and that, in fact, only about one thousandth part of the genetic material was sensitive to the mutagenic action of X-rays. On the other hand, the target hypothesis found support in experiments with neutrons. The calculated sensitive region was so small that neutrons would in general produce more than one ionization inside it, and if one ionization was sufficient to produce a mutation, neutrons should, dose for dose, be less effective than X-rays. This was, indeed, found to be so ; but recent experiments with better methods of dosimetry and genetical analysis do not bear out these earlier findings.

The target theory was subsequently extended to other causes of mutation, and it was postulated that a mutation is produced whenever a supply of energy—electrical, thermal or chemical—lifts the gene molecule from its original stable configuration over an energy barrier into the new stable configuration of the mutated state.

The target theory, which had been put forward by physicists, attracted more physicists and made them interested in genetics. Genetics has benefited from their contributions, e.g. from the stimulating little book by Schrödinger " What is Life ? " or from Lea's monumental " Actions of Radiations on Living Cells." Geneticists were not uniformly enthusiastic about the target theory. Some of them at least realized that the application of a purely physical theory to the highly complicated processes in a living system carries with it the danger of over-simplification, and may prove a barrier to unprejudiced research. In particular Muller warned from the start against the rigid interpretation of mutations in terms of " hits " inside a fixed target volume. He pointed out that of the two main premises of the target theory—only ionizations inside the target volume produce mutations, and every ionization inside this volume is effective—neither is likely to be correct.

Recent findings in radiochemistry and genetics have made it impossible to apply the orthodox target theory to mutagenesis in general. Radiation chemistry has shown that much of the action of ionizing radiations on organic molecules in aqueous systems is mediated by activated water radicals. Genetics has found that the mutagenic effectiveness of a given dose of radiation—the sensitive volume in terms of the target theory—can be greatly modified by incidental conditions of treatment, such as oxygen supply, temperature, or developmental stage of the treated cell. Moreover, ultra-violet light, which does not produce ionizations, and a whole host of chemicals have been found to be mutagenic. Most geneticists incline to the belief that mutations may be produced in various ways, only one of which consists in providing energy for what Schrödinger calls isomeric transition in a gene molecule. For the special case of ionizing radiations it remains necessary to postulate that the effective ionization or activation takes place in close neighbourhood of the responding gene.

This criticism of the target theory does not, of course, invalidate the fundamental observations on which it was based. In particular, it remains true that the frequency of X-ray induced mutations increases linearly with dose as measured in r-units, and that it is independent of the way in which ionizations are distributed in time. This leads to conclusions of great practical importance. If the linear dose-effect curve may be extrapolated to even the lowest doses—and recent experiments have verified it for doses as low

as 25 r—there is no lower threshold to the mutagenic action of X-rays, and even the lowest dose produces mutations exactly in proportion to its magnitude. In addition, it makes no difference how a given dose is distributed. Thus a dose of 300 r will produce the same number of mutations whether it has been received in the reproductive organs of one atom bomb survivor, or in those of 300 persons each of whom received 1 r in his reproductive organs, or in those of one person who for 30 years received 10 r yearly. Strictly speaking, this is only true when reproductive cells of the same type are compared, e.g. young male germ cells or spermatogonia ; for the genes differ in sensitivity according to the type of cell in which they occur.

Large chromosome re-arrangements follow a different law of increase with dose. A large re-arrangement is produced when two or more chromosome breaks have occurred in the same cell nucleus and the broken ends have joined up in a new way. The breaks themselves increase in frequency in proportion to the dose ; but the re-arrangements are secondary effects requiring two independent primary events, and their frequency increases therefore approximately as the square of the dose. The qualification " approximately " comes in because biological systems never are free from complexities which cause deviations from simple physical laws. At low doses, re-arrangements are very rare, and even high doses produce few re-arrangements if they are given at low intensities ; for in most cells broken chromosomes have a tendency to restitute, and the longer the time interval between the first and second break in the same nucleus, the smaller the probability that the first break will still be available for rejoining with the later one. Chronic irradiation at a low dose rate is therefore not likely to produce appreciable numbers of re-arrangements.

Let us now consider what types of genetical effect are to be expected in a human population which is exposed to radiation, and in what frequencies these effects are likely to occur after a given dose. We meet here with the difficulty that very little is known about mutation in man, and nothing at all about X-ray induced human mutations. We have to base our conclusions on what is known about lower organisms, especially *Drosophila*, and to some extent also on mice. To many persons it may seem hazardous or even impossible to extrapolate findings on flies to expectations in a human population ; but this scepticism is only partially justified. It is true that much research on higher animals and man himself will have to be carried out before we can arrive at reliable estimates of the danger to which we expose posterity by the use of ionizing radiation in industry, therapy, and defence. But genetics perhaps more than any other branch of biology deals with laws which apply to all organisms from viruses to man. In particular, mutations and chromosome re-arrangements occur in all organisms which are exposed to ionizing radiation ; there is not the slightest doubt that they occur also in irradiated human cells. Also the relationship between dose and frequency of mutations or re-arrangements is the same in all tested organisms and will, doubtlessly, be the same in man.

The actual types of mutation will, of course, differ between a fly and a human being. But certain ways of classifying mutations are valid for all organisms. One is the classification into dominant and recessive mutations. This is necessitated by the fact that all sexually produced organisms—men as well as flies—contain duplicate sets of chromosomes and genes, one derived from the father, the other from the mother. It has been said before that two partner genes always affect the same developmental process, but as a result of previous mutations they will often do so in different ways. In such cases the joint effect of the two different partners depends on their relative abilities to influence development. Sometimes both are about equal in strength and produce an intermediate result : a Shorthorn cow with one gene for red coat and a partner gene for white coat is roan. Often one gene dominates development to the exclusion of the other ; such a gene is called dominant, and its partner recessive. In man the gene for polydactyly, that is the possession of extra

fingers or toes, is dominant over its normal partner gene ; a person with only one such gene has extra fingers or toes. More often it is the normal gene which is dominant over the mutated one. Albinism, e.g., is due to a recessive gene which in many species, including man, arose through mutation. Individuals with two albino genes are albinos ; those with one albino gene and a normal partner gene are normally pigmented.

How soon a new mutation becomes manifest depends on whether the new gene is dominant or recessive. A dominant mutation is detected in the first individual which received the mutated gene in either egg or spermatozoon. A recessive mutation may not be detected for many generations ; for the first reproductive cell with the new gene is likely to fertilize or be fertilized by a cell with the normal partner gene so that the effect of the mutated gene is masked in the developing individual. The gene, however, is still there, and when the individual forms reproductive cells, half of them carry it and transmit it to the next generation. There, again, its effect will probably be masked, and so it may go on through many generations until finally an individual is produced which inherits the mutated gene from both parents and manifests its effect. Usually, therefore, many generations will elapse between the occurrence of a recessive mutation and its detection. This interval may be shorter in two cases ; first when the same mutated gene is already carried by many members of the population as a result of previous mutations ; and second when inbreeding increases the chance that two individuals mate which have received the newly mutated gene from their common ancestor. Both these possibilities are exploited for the detection of recessive mutations in experiments on animals and plants.

A second way in which mutations may be classified is according to their effect on viability. A mutation may be beneficial, neutral, moderately harmful, or lethal. In addition it may or may not have some outwardly detectable effect on, say, body size or eye colour.

Outwardly visible mutations with or without associated effects on viability are exceedingly rare, dominant ones even more so than recessive ones. Much more frequent are dominant or recessive lethal mutations. Dominant lethals kill the first individual which received them in either egg or spermatozoon. In *Drosophila* they are detected as fertilized eggs which fail to hatch, in mice as early abortions after irradiation of either parent. A recessive lethal does not kill the first individual which received it. Depending on the mating scheme, the lethal may be carried through several or many generations until an individual which inherits it from both parents dies of its effect. It has, however, been observed that in *Drosophila* many recessive lethals have a slight harmful effect even on those individuals in which their action is largely suppressed by the presence of the normal partner genes. In two independent investigations, the average reduction in viability of such carriers of recessive lethals was about 4%. This finding is very important for the assessment of radiation damage to future generations. By far the most frequent mutations are the harmful ones which, without causing any visible abnormality, impair health and resistance of the individual, so that it becomes more liable to die from one of the many hazards of living.

This preponderance of harmful or lethal effects is characteristic not only of X-ray mutations in all tested species, but also of spontaneous mutations. It is easily understood from the evolutionary point of view. Mutations are random changes in the genetic material which cause random deviations from the natural processes of development. In every existing species these processes have become so delicately balanced and interwoven through millions of years of natural selection that any change in one of them is likely to be a change for the worse.

To complete the catalogue of radiation damage in animals I want to add that two types of re-arrangement have harmful effects. One is deficiencies, that is losses of chromosome material. Depending on the size of the deleted chromosome piece, deficiencies act as dominant or recessive lethals. The other is translocations, that is exchanges of pieces

between chromosomes. Some of these act as dominant lethals ; others result in offspring which has reduced fertility, and this semi-sterile condition is inherited as a dominant. In mice X-radiation has produced many lines in which about half the members of each generation—males as well as females—have drastically reduced fertility.

How far can these findings be used to assess the expected radiation damage to human posterity ? Although the actual proportions of genetical effects will probably not be the same in flies and men, or even in mice and men, there is no doubt that also in man the great majority of radiation induced mutations will be lethal or harmful, and that visible mutations will be very rare. It is true that in Japan some abnormal children were born to women who had been exposed to an atom bomb explosion during pregnancy ; but these children had suffered direct radiation damage *in utero*. The abnormalities which they developed are not due to genetical changes, and if such an ante-natally damaged child should live to reproduce, it will not transmit the radiation effect to its progeny. Exposed men, or women who had been exposed before pregnancy, had no more abnormal babies than unirradiated parents in the same population. This was only to be expected from the rarity of dominant visible mutations.

Perhaps less to be expected was the finding that also the incidence of abortions and miscarriages was not in excess of that of the control population—again excepting women who had been exposed during pregnancy. In mice, embryonic death through dominant lethals is the most easily observed result of irradiation. In fact, dominant lethality is a relatively much more important component of radiation damage in the mouse than in *Drosophila*, possibly because the mouse has five times as many chromosomes. Man has even more chromosomes than the mouse, and it is highly probable that such an intensive radiation as an atom bomb explosion would produce many dominant lethals in both male and female human reproductive cells. The reason why this effect should have remained undetected can be inferred from the work on mice. There dominant lethals kill the embryo at a very early stage of development ; if this happens also in man, abortion will remain unnoticed.

Next to dominant lethality, translocations causing inherited semi-sterility are the most striking genetical result of irradiation of mice. It is too early to say whether inherited semi-sterility occurs among the children of atom bomb survivors. Quite possibly this will not seem to be the case. Infertility in these cases is caused through early abortions of about half the offspring, and this may remain unnoticed in a woman. In any case, even a drastic reduction of reproductive potential is not likely to be a source of unhappiness or concern in populations in which family size is kept purposely low.

Some offspring of irradiated mice are completely sterile. If this, too, should be found among children of irradiated humans, it may cause personal unhappiness, but no danger to posterity ; for sterility is a defect which eliminates itself.

The actual genetical damage which we have to expect from the irradiation of human populations is of a much less spectacular kind. It is the production of harmful or lethal recessives which may be carried through a great many generations before they claim their victims. A recessive lethal will kill the first individual which receives it from both parents. A recessive harmful gene only increases the probability that those who carry it in double dose will die early ; eventually, however, it too will result in what Muller has called a " genetic death." And on the way to this end it will have produced a track of individuals who in some way, physically or mentally, are slightly inferior to what they would have been without this gene. In addition, it is likely that in man as in *Drosophila* harmful recessive genes impair viability slightly even in those persons who carry them only in single dose together with a normal partner gene. Since many more persons inherit a harmful gene from one parent than from both, this small effect will in its totality outweigh the much more drastic, but much more rare effect on persons who have a harmful gene in duplicate.

Human variation is so great that it will hardly be possible to pinpoint those persons whose mental or physical abilities are slightly impaired by harmful genes in double dose or by harmful or lethal genes in single dose. Yet, if generation after generation ionizing radiations add new harmful genes to those which are already carried by the human population and which constantly arise from natural causes, some degree of genetical deterioration is unavoidable, even if it may be spread out over very many generations. Medical progress may to some extent mask this deterioration, but it cannot prevent it.

You see that the popular idea of genetical radiation damage is quite wrong. There is no need to be afraid that more monsters or imbeciles will occur among the children of irradiated persons. The real danger is much more insidious : to appreciate it as a danger requires not only some genetical knowledge, but even more a sense of responsibility for the welfare and happiness of human generations which, measured by our short individual life span, will live in a very remote future.

Those who have this knowledge and this sense of responsibility are faced with the difficult problem of deciding on a " genetically permissible " dose of ionizing radiation. Only a compromise solution is possible ; for there is no lower threshold to the mutagenic action of radiation, and even if we were to abandon completely the use of ionizing radiation, cosmic radiation and naturally occurring radioactive substances would continue to produce mutations. At present we can no more than guess at the actual numbers of mutations which a given dose of X-rays produces in human reproductive cells. We neither know the number of human genes nor their mutation rates under irradiation. It appears that mouse genes are considerably more radiosensitive than *Drosophila* genes, and it seems reasonable to assume that human genes will resemble those of the mouse rather than of *Drosophila*. On this basis Muller has estimated that 1 r produces about 6×10^{-4} mutations in one human reproductive cell, and that about 80 r double the frequency of naturally occurring mutations. At present the permissible dose in atomic energy establishments is 15 r per year. This is meant to protect the worker against direct radiation damage, not his progeny against genetical damage. The " genetically permissible " dose will almost certainly have to be considerably lower ; for our responsibility in this matter is so great that our lack of precise information should induce us to err on the side of caution.

ACKNOWLEDGEMENTS

Fig. 1 is reproduced, by permission, from *An introduction to modern genetics*, by C. H. Waddington (London : Allen and Unwin). Figs. 2–5 are reproduced, by permission, from *Le mécanisme des mutations et la structure du gène*, by N. W. Timoféeff-Ressovsky (Paris : Nermann & Co.).

The History of the Microscope to the end of the 19th Century*

By J. A. CHALDECOTT, M.Sc., A.Inst.P.

(*Assistant Keeper, Science Museum, London*)

BEFORE DEALING with the development of the microscope during the 17th, 18th and 19th centuries, some mention should be made of the idea that the origin of the microscope is lost in antiquity. Although this idea has been put forward by several writers, it is not borne out by evidence. Admittedly the Ancients made use of burning glasses but they certainly had no idea of the physics of the lens, attributing the phenomenon to a property of the glass itself rather than to the curvature of its surfaces. As for the method of grinding and polishing used by the Ancients, in which the glass was held against a revolving lap or buff, this process could hardly have led to the production of spherical surfaces that were sufficiently true to yield optical images reasonably free from distortion.

A study of the early history of optics would seem to indicate that the invention of the microscope must be attributed to a very much later period. Euclid (about 300 B.C.) applied the laws of reflexion to explain the action of plane and curved mirrors but it was not until the second century A.D. that Ptolemy made the first experiments on refraction, his investigations being limited to refracting media bounded on both sides by plane surfaces. About 1000 A.D. Alhazen the Arab extended Ptolemy's work to include curved surfaces, but apart from treating the case of refraction through a transparent sphere his other investigations were confined to refraction at single spherical surfaces.

The manufacture of any efficient optical instrument could scarcely have been possible before the introduction of a method for grinding and polishing which involved the use of a spherical tool. It appears likely that this advance in technique took place towards the end of the 13th century, for it is about then that we have the first mention of the use of spectacles. The fact that during the ensuing three centuries no one seems to have applied a magnifying spectacle lens to the study of Nature is not altogether surprising, bearing in mind the apparent lack of interest in natural phenomena that was characteristic of the mediaeval period.

ORIGIN OF THE MICROSCOPE

The invention of the microscope, in two different optical forms, is generally attributed to the period 1590 to 1610. The first instrument, made about 1590, was the work of two spectacle-makers, Zacharias Janssen and his son John, both of whom lived at Middelburg, Holland. Their microscope consisted of a biconvex objective and a plano-convex ocular lens. Figure 1 shows a microscope found in Middleburg in 1886 which is thought to be an early form of Janssen's invention and may possibly have been the work of the inventors. It gave a magnification of three diameters when closed and nine diameters when fully extended.

The second type of microscope, due to Galileo, was an adaptation of the telescope which he developed in 1609, only a few

* A lecture given to the Midland Branch of the Institute on November 16, 1955

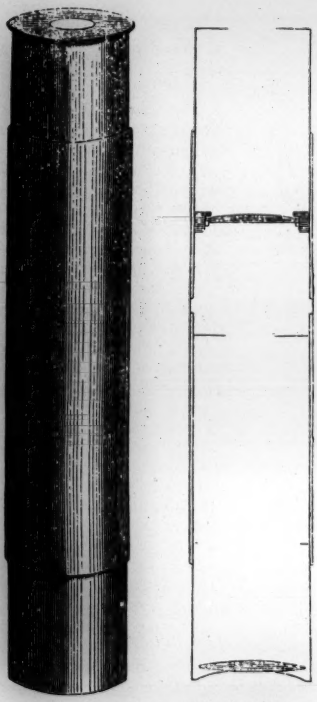

FIG. 1. *Middelburg microscope (after Harting)*

months after hearing a rumour of the invention of such a device in Holland. We know from the writings of one of Galileo's pupils (1610) that his master also used this telescope as a microscope, and four years later Galileo himself supplied the information that this was accomplished by extending the length of the telescope tube from the two feet normally required for astronomical observations to between 10 and 16 feet for use as a microscope.

NAMING OF THE MICROSCOPE

Several terms were current in the early part of the 17th century to describe both telescope and microscope: *occhiale* and *occhialino* in Italian, *lunette* in French, and *perspicillum* in Latin. It was generally left to the reader to decide from the context which instrument was meant in any writings. The name *microscopium* was suggested by Giovanni Faber, a member of the Academy of the Lynx, in a letter dated April 13, 1625. The name subsequently appeared in a book published in 1630 and had become generally adopted by 1650. A few well-known English authors of the 17th and 18th centuries favoured the word *engyscope*, and the use of this term was continued by Dr. C. R. Goring, one of the patrons of the microscope during the 19th century. In later years Goring applied this term primarily when speaking of reflecting microscopes of the Amici pattern, and by the end of that century the name had come to be reserved almost exclusively for describing that particular form of instrument.

EARLY HISTORY OF THE MICROSCOPE

For several years after its invention the compound microscope attracted little attention in the scientific world, due mainly to the fact that interest was centred on the revelation of the heavens as exposed by the newly invented telescope. But equally important may have been the fact that poor results were obtained with the microscope due to its inherent disadvantages of spherical and chromatic aberration. An attempt to reduce spherical aberration was made by René Descartes (1637) who suggested the use of plano-convexo-hyperbolic instead of spherical lenses, but he was unable to find opticians capable of working all the lens forms required, either in France or in Holland, and he seems thereafter to have lost interest in the project.

The value of the microscope as an instrument for research became recognized after the publication of Robert Hooke's *Micrographia* (1665). His microscope (see Figure 2) had a double convex objective and an eyepiece consisting of a large double convex field-lens together with a smaller eye-lens. The function of the field-lens was to enlarge the field of view, and it was removed altogether when fine structures were to be observed. Hooke managed to reduce spherical and chromatic

FIG. 2. *Hooke microscope (from "Micrographia")*

aberration to some extent by placing a diaphragm with a very small aperture close behind the objective, a device that cut down the amount of light entering the instrument and made it necessary to employ a condensing system for illuminating opaque objects. This consisted of a plano-convex glass lens and a glass sphere filled with brine. The microscope objective was focused by rotating the body-tube about the optic axis of the instrument so that the nose-piece turned in the collar which was attached to the pillar by a ball-and-socket joint. Eyepiece focusing was effected by means of the draw-tubes.

Excellent as was the work done by Hooke with his microscope, the instrument had several disadvantages, most important being the method of focusing which was very liable to upset the optical alignment. To eliminate this defect, Hevelius (1673) modified the design by providing a fine-adjustment screw by which the body-tube could be raised or lowered without at the same time undergoing any rotation.

SIMPLE MICROSCOPES

Microscopists of the Classical Period (1660–1725) found the compound microscope suitable only for work at low and medium powers, whilst for high powers they had to resort to the use of simple microscopes. The exceedingly small lenses required for these simple microscopes were prepared either by grinding and polishing small chips of glass, or by heating thin filaments of glass until they melted into spherical drops in the flame of a spirit lamp ; alternatively, lenses were sometimes obtained by making use of small drops of various liquids.

The most outstanding worker of this period was Antony van Leeuwenhoek who began reporting his microscope observations to the Royal Society in London in 1673. Leeuwenhoek's lenses were obtained by grinding and polishing, and they were mounted between two metal plates riveted together. The general design and mounting for the object can be seen in Figure 3. The arrangement of screws and their fastenings permitted movement of the object to be controlled in any direction whatsoever. It was generally Leeuwenhoek's practice to make a separate simple microscope for each biological specimen, and a very large number of instruments were therefore prepared during his lifetime ; when he died, in 1723, he left no fewer than 550 microscopes. Leeuwenhoek steadfastly refused to divulge any details concerning his lenses, but from an examination of 26 of his microscopes which subsequently came into the possession of the Royal Society it became known that his lenses were prepared by grinding and polishing ; they ranged from 1/20 to 1/5 inch and had magnifying powers from $\times 160$ to $\times 40$. The strongest Leeuwenhoek

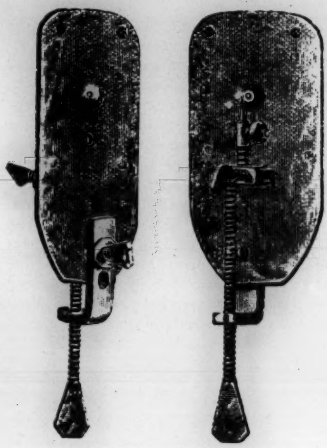

FIG. 3. *Leeuwenhoek microscope*

lens still preserved in Holland has a power of ×275 and a resolution of 1·4 microns.

The most common simple microscope, and one that came to be widely used throughout the 18th and 19th centuries, was of screw-barrel design. The original form, due to Nicolaas Hartsoeker (1694), is shown in Figure 4, where the object slide is held between the two thin brass plates E and F which fit inside the body-tube and are pressed together by the action of the helical spring. The positions of the microscope lens P and condensing lens N could both be varied in relation to that of the slide itself by means of the screw-barrel devices. Eight years after the appearance of Hartsoeker's design, James Wilson introduced a similar model which differed from that of Hartsoeker principally in the absence of any means for varying the position of the condensing lens. Wilson's design was cheap to make and yet gave a good performance. Examples known to have been made about 1740 were capable of yielding a magnifying power of ×400 and a resolution of 1·7 microns.

The first screw-barrel microscopes were intended to be held in the hand, but subsequently it became the practice to mount the instruments on small scroll stands to enable the observer to have both hands free whilst carrying out and recording his observations. In its various forms the screw-barrel instrument maintained its popularity for about 100 years during which period it proved far superior to the compound microscope.

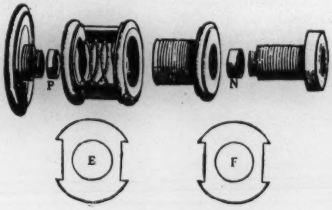

FIG. 4. *Hartsoeker microscope*

EVOLUTION OF THE COMPOUND MICROSCOPE STAND

In the latter part of the 17th century there were two types of microscope stand in general use. One of these, typified by the design of Hooke, had the body-tubes mounted alongside a pillar which rose from a box-foot. The other pattern, initially more popular on the Continent, had the body-tubes supported on a tripod base. These two designs developed independently for more than 150 years until finally the better features of both were combined to provide the design with which we are familiar at the present day.

About 1693, John Marshall introduced the first major changes in the design of the Hooke microscope. Marshall incorporated the screw-focusing device of Hevelius, he removed the stage from the base of the instrument and mounted it on the pillar supporting the body-tubes, he transferred the ball-and-socket joint to the base of the pillar so that inclination of the instrument could be made without upsetting the optical alignment of lenses and object, and he also introduced a single condensing lens beneath the stage for use with transparent objects. When such objects were to be viewed by the Marshall microscope, the instrument was arranged to over-

hang the edge of the table on which it stood, and a candle as source of light was placed on the floor below the object ; alternatively, a hole was sometimes cut in the top of the table and the microscope stood directly above this opening with the candle below. It was not until 1716 that Christian Hertel introduced a plane mirror beneath the stage so that the candle could be placed on the table alongside the microscope.

Between 1725 and 1730 Edward Culpeper brought out a microscope based on the tripod design which was to become exceedingly common. Examples made about 1740 have been found to provide a magnifying power of $\times 275$ and a resolution of 5 microns. The stage of the Culpeper microscope was supported on a tripod stand and had a hole cut in the centre which corresponded to the hole in the table sometimes employed with the Marshall microscope. On the centre of the baseplate was mounted a substage mirror of concave form, the first occasion on which a concave mirror had been so employed. Arising from the upper surface of the stage was another tripod support for the body-tube. Focusing was effected by sliding the draw-tubes carrying eyepiece and objective mount inside the body-tube. It was not until some years later that other instrument makers added a system of focusing by rack and pinion.

About 1738 Benjamin Martin introduced a pocket microscope from which was derived the " drum " microscope that afterwards became so popular. This pattern can be considered as a modification of the Culpeper microscope in which the outer body-tube has been extended to the base of the instrument, and apertures provided for illuminating the substage mirror and for inserting the object-slides. The early Martin drum microscopes were of wooden construction with paper or vellum tubes. Later forms were of an all-brass construction. The brass form in its turn led to a more modern type of drum microscope where much of the superfluous metal shielding was removed and rigidity still preserved by incorporating a stout brass pillar placed to one side of the instrument. Stages in the development of the tripod pattern of compound microscope are to be seen in Figure 5.

The first significant change in the Marshall design was made in 1744 by John Cuff who provided a fixed pillar and mounted it at one corner of the box-foot which also carried the substage mirror. The Cuff design was a worthy competitor for the contemporary Culpeper microscope, for although it only gave a magnifying power of $\times 140$, it possessed a resolution of 2·5 microns. The Cuff pattern was copied by other instrument makers, some of whom later eliminated the box-foot and replaced it by a three-legged folding metal base. In 1754 Francis Watkins arranged all the optical components and stage of the microscope on a stout rod which was hinged to the top of a pillar rising from a tripod foot, and this plan was copied extensively during the latter half of the 18th century. Three stages in the development of this type of microscope stand are shown in Figure 6.

The modern form of stand used for " student " microscopes can be traced back directly to an amalgamation of the hinged pillar design introduced by Watkins with the more stable arrangement of the drum microscope. The first microscope to combine these properties and to have the now familiar U-shaped foot was made by Edmund Hartnack about 1840. Most of the improvements since that time have been brought about by the need to develop better fine-adjustment mechanisms and more efficient types of substage condenser, both of which became necessary after the introduction of immersion objectives about 1850.

REFLECTING MICROSCOPES

Little change in the optical design of refracting microscopes took place for about one hundred years after the introduction of the Hooke microscope. This can be attributed to the fact that following Isaac Newton's experiments on the nature of colour, published in the *Philosophical Transactions* of 1672, it seemed impossible to eliminate chromatic effects except by the abandonment of refracting systems. Newton himself proposed the construction of a reflecting microscope in

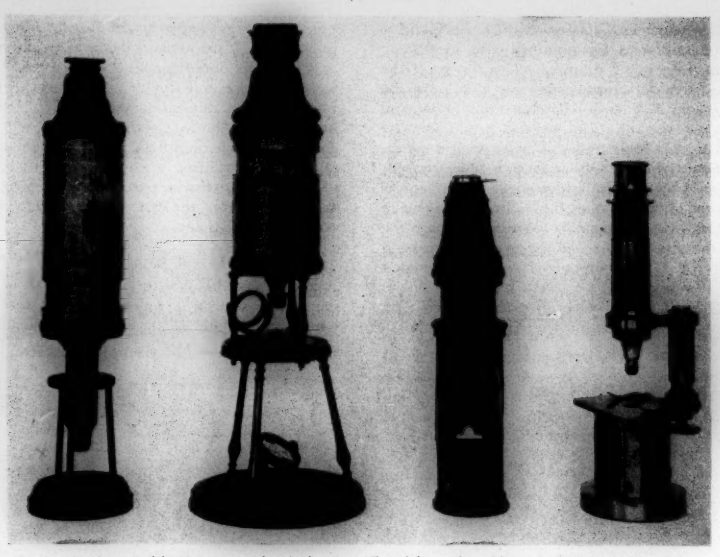

FIG. 5. *Development of the microscope stand—tripod pattern. From left to right : Mann microscope (c. 1680) ; Culpeper microscope (1725–30) ; Martin drum microscope (c. 1740) ; Oberhaeuser microscope (c. 1830)*

1672, but did not apparently carry his proposals into effect. During the 18th century, however, a number of reflecting microscopes were designed and made, notably by Robert Barker (1736), Robert Smith (1738), and Benjamin Martin (1759). Good reflecting microscopes were produced about 1820 by Jean Amici and subsequently improved by James Cuthbert, but though several other designs were prepared in this country and on the Continent, the discovery by Joseph Jackson Lister, in 1827, of the principle of making aplanatic achromatic lenses rendered further experiments on reflecting systems unnecessary.

ACHROMATISM OF THE MICROSCOPE

The first achromatic lens combination was made in 1729 by Chester Moor Hall, and four years later two optical instrument makers, Edward Scarlett and James Mann, were given the job of grinding components for a 2½-inch diameter telescope objective. The result was quite successful, but though the principle of the achromatic lens was then known to several instrument makers, none seems to have paid much attention to the discovery. About 1755, S. Klingenstierna wrote to John Dollond and persuaded him to carry out experiments which led, three years later, to the submission of a paper to the Royal Society wherein Dolland announced his own production of achromatic telescope objectives. Thanks mainly to the initiative and enterprise of Dollond, achromatic telescopes soon superseded the non-achromatic types.

The application of achromatic lenses to the microscope did not take place so rapidly, however. The first microscope with achromatic objective was made in 1759 by Benjamin Martin but proved very disappointing since,

on comparison, its performance was found to be inferior to that obtained with a reflecting microscope of the day. The theory of the achromatic microscope was developed by Euler, Füss and Klügel in the 1770s and gave rise in 1791 to the production by François Beeldsnyder of an air-spaced achromatic triplet. One of the difficulties encountered by makers of microscope objectives was that of maintaining the optical alignment of their lens components fixed even though the objective might be subject to some percussion in use. The components were at first housed in brass cells which screwed together, but in 1824 Charles Chevalier introduced the process of cementing with Canada balsam.

In a paper presented to the Royal Society in 1830, J. J. Lister explained how aberrations of achromatic doublets could be corrected by means of a second doublet. The work of Lister, though not immediately recognized by all, opened the way to the manufacture of good microscope objectives. One of the first to profit from Lister's work and to make microscope objectives according to his designs was Andrew Ross, the first of these objectives appearing in 1831.

IMMERSION OBJECTIVES

Amici was the first to make use of oil immersion with a compound microscope, some time before 1850, but the amateur

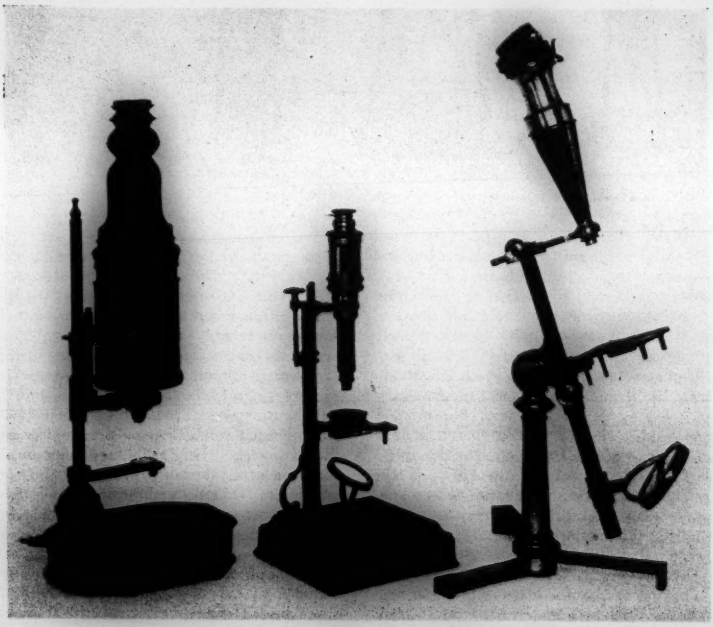

FIG. 6. *Development of the microscope stand—pillar pattern. From left to right : Marshall microscope (1715) ; Cuff microscope (1744) ; Adam's "Universal" microscope (c. 1790)*

microscopists of his day disliked the use of oil because it spoiled their preparations and Amici therefore converted his system into one for water immersion. These Amici water-immersion objectives were suitable only for one thickness of cover glass but in 1859 Hartnack provided an objective (N.A. almost 1·0) which could be corrected for various thicknesses of cover glass. Other makers provided similar immersion objectives ranging from 1/25 to 1/50 inch with N.A. approaching 1·0. These objectives required the use of very thin cover glasses, however, and this led Abbe (1873) to doubt the value of any immersion objective of less than 1mm focus. In the same year Tolles, in America, produced a 1/5 inch oil-immersion objective (N.A. 1·25).

Abbe's diffraction theory of the microscope appeared in 1877 and one year later J. W. Stephenson and Ernst Abbe both introduced a homogeneous immersion objective. But probably the most significant advance in microscope optics towards the end of the 19th century was the appearance, in 1886, of the apochromatic objective (3mm, N.A. 1·40). This was made to Abbe's design using glass specially prepared in the Zeiss works by Otto Schott.

BINOCULAR MICROSCOPES

In an article of this length it is not possible to deal with every aspect of the history of the microscope and only the broad principles of development during the first three centuries of its existence have been touched on. The optics of the various forms of binocular microscope make an interesting study and many of the designs come well within this period. As early as 1671 Chérubin d'Orléans figured a binocular microscope comprising two body-tubes inclined together at a small angle and equipped with paired objectives of 1 inch focus. From the optical arrangement it is clear that this instrument must have given inverted pseudo-stereoscopic images. But little interest appears to have been aroused by this design and it was not until after Charles Wheatstone had read his paper on binocular vision to the Royal Society in 1838 that microscope manufacturers gave any serious attention to the production of binocular instruments.

The first stereoscopic binocular microscope was devised by J. A. Riddell in America in 1851. It had convergent tubes, the pencil of light emerging from the single objective being divided geometrically by means of prisms. Two years later the firm of Nachet and Son, in Paris, introduced another form in which parallel tubes were employed. By far the most popular design in this country was due to F. H. Wenham, who was optical adviser to the firm of Ross. This was a convergent tube model. It was manufactured in large numbers by Ross, who also undertook to convert monocular microscopes of his own make to the binocular system of Wenham.

Several other optical arrangements were devised in the later years of the 19th century, and for details of these the reader is referred to an article by F. C. Wise entitled " The Development of the Binocular Microscope " which appears in *The Journal of the Quekett Microscopical Club*, Series 4, Volume 2, No. 6 (March, 1949).

ACKNOWLEDGEMENT

The illustrations are reproduced by courtesy of the Director of the Science Museum, London.

News of Members

FELLOWS

H. W. French has been promoted to Staff Inspector in the Ministry of Education.

E. Griffiths is now a member of the General Board of the National Physical Laboratory, Teddington, Middx.

H. Kolsky has taken up an appointment as visiting Professor of Engineering at Brown University, Providence, Rhode Island, U.S.A.

D. Parkinson is now a consultant with the United Carbon Company of Charleston, West Virginia, U.S.A.

C. F. Sharman has been appointed Scientific Adviser to The Imperial Tobacco Company Ltd., Bristol.

ASSOCIATES

G. F. Adams has been appointed a member of the Board of A. Gallenkamp and Company Ltd., London.

S. W. Conning is now with Standard Telephones and Cables Pty., Ltd., Sydney, Australia, as an Engineer.

A. W. Cronshaw has taken up an appointment with the British-American Tobacco Company Ltd.

I. Davies has been appointed Headmaster of the Oystermouth Secondary School, Mumbles, Swansea.

Pamela Dunsmuir has been appointed Lecturer in Physics at Rugby College of Technology and Arts.

A. J. Drummond is now a Chief Research Physicist with The Eppley Laboratory, Inc., Newport, Rhode Island, U.S.A.

C. R. Evans has taken up a post with Imperial Chemical Industries Ltd., Central Instruments Establishment, Whitchurch Hill, Oxon.

D. J. Evans is now working in the Department of Metallurgy, University College of Swansea.

K. D. Exley has been appointed Headmaster of Creighton School, Carlisle.

R. C. Faust has recently taken up an appointment with The Aluminium Laboratories Ltd., Banbury, Oxon.

I. Flinn is now employed at Mullard Research Laboratories, Salfords, Surrey.

L. C. J. Fricker has joined the staff of the Guided Weapons Department of Vickers-Armstrongs (Aircraft) Ltd., Weybridge, Surrey.

W. Gemmell is now working at the Atomic Energy Authority establishment at Sellafield, Cumberland.

K. Hickson is now in charge of the X-ray Department of the Research Laboratories of Pilkington Brothers Ltd., St. Helens, Lancs.

B. Hogley is now at the Scottish Woollen Technical College, Galashiels, as a Research Assistant.

J. Leak is now employed by Canadair Ltd., Montreal, Canada.

H. C. Lewis has joined the staff of Cranbrook School, Kent, as Senior Physics Master.

D. Macfie has recently taken up a post with British Nylon Spinners Ltd., Pontypool.

T. A. Margerison is now Managing Editor of *British Chemical Engineering* (Heywood and Company Ltd., London).

K. J. Marsh is working at the Research Station of the British Petroleum Company, Sunbury-on-Thames, Middx.

K. L. Selig is now at Selig Electro-Magnetics Ltd., London.

R. Scott has taken up an appointment as Senior Scientific Officer at the Atomic Energy Research Establishment, Harwell, Berks.

K. H. Stark is now working in the Insulation Department of the English Electric Company Ltd., Stafford.

D. W. Stops has recently taken up an appointment at Bell's Asbestos and Engineering Ltd., as a Physicist.

E. L. Poupinel de Valencé has taken up an appointment as Medical Physicist between Johannesburg General Hospital and the University of Witwatersrand.

H. Wilkinson has recently taken up the appointment as Principal of the Harris Institute, Preston, Lancs.

G. I. Wright is now working at the Mullard Research Laboratories, Salfords, Surrey.

GRADUATES

J. Arkley is now with Hayeshaw Ltd., Manchester, as an Operational Research Physicist.

J. W. Bradley is taking up a post as Physics Master at Maltby Grammar School, Yorks.

A. Bradshaw has recently joined the staff of the Research Laboratories of Ferranti Limited, Wythenshawe, Lancs.

A. Browne is now doing research at Mullard Research Laboratory, Salfords, Surrey.

C. Cowell is now employed by Honeywell-Brown Ltd., as a Sales Engineer.

W. G. Ferrier has taken up a post at the Atomic Weapons Research Establishment, Aldermaston, Berks.

E. L. Freeman is now employed in the Research Department of Kelvin Hughes Ltd., Barkingside, Essex.

J. J. Gameson is taking up a new post as a Technical Author with Ultra Electric Ltd., Acton.

D. A. Humphreys has now joined the staff of the Technical College of Monmouthshire, Crumlin, as an Assistant Lecturer in Physics and Mathematics.

P. Kalman is now a Research Assistant at the Imperial College of Science and Technology, London.

J. M. Lowe is now employed as a Junior Engineer in the Radiation Section of the Research Department of Metropolitan-Vickers Ltd., Manchester.

M. W. McElhinny is now with British Dielectric Research Ltd., London, as a Scientific Officer.

R. J. Miller has taken a post with the Atomic Weapons Research Establishment, Aldermaston, Berks, as a Scientific Officer.

K. Parramore is now working at British Thomson-Houston Co. Ltd., Rugby.

Anne Potter is now a Scientific Officer at the Atomic Energy Research Establishment, Harwell, Berks.

J. B. Rick is working in the Research and Development Branch of the U.K. Atomic Energy Authority, Sellafield, Cumberland, as a Scientific Officer.

CORRECTIONS

J. R. Whitehead (*Fellow*)—on page 26 of the January issue—for "a Director" read "Director of Research."

R. D. Moore (*Associate*)—on page 294 of the December, 1955, issue — for "Assistant Lecturer" read "Lecturer."

J. F. Sayers (*Graduate*)—the whole reference on page 26 of the January issue should be deleted. Mr. Sayers is still employed at the Northampton Polytechnic, London.

Branch and Group News

London and Home Counties Branch

Mr. B. S. Cooper has retired from the Honorary Secretaryship of the Branch after serving for five years. The new Honorary Secretary is Mr. D. T. R. Dighton (*Associate*), of Kodak Limited.

Midland Branch

The Branch Annual Dinner will be held on March 22 at the University Union, Birmingham. The dinner will be at 7.30 p.m. following a reception at 7 p.m. by the Branch Chairman, Professor P. B. Moon and Mrs. Moon. The principal guests are Dr. R. Beeching (*Fellow*), Chairman of I.C.I. Ltd. (Metals Division), and Mrs. Beeching. After the dinner, Mr. G. de Q. Robin (*Fellow*) will give a talk based on his experience of polar expeditions.

Further details may be obtained from the Branch Honorary Secretary.

Education Group

The Education Group Conference on April 5 and 6 will be devoted to two main topics. On the first day the general subject is "The Teaching of Nuclear Physics." Papers will be given by Professor P. B. Moon and Professor W. E. Burcham, Mr. A. L. Chick, Dr. J. Topping and Dr. J. W. Warren, and Mr. J. A. H. Peacocke. In the evening Dr. J. M. A. Lenihan will speak on "Impressions of the Geneva Conference on the Peaceful Uses of Atomic Energy." The following day the main subject is "The Adequacy of the General Certificate of Education Advanced Level Examinations as Criteria for University Selection." The speakers are Mr. J. A. Ratcliffe and Miss K. E. Parks and speakers on related topics will be Professor M. R. Gavin and Dr. N. Thompson.

Subject to the limit of accommodation, attendance is open to all members of the Institute and to non-members who pay the required conference fee. Programmes and forms of application to attend may be obtained from the Deputy Secretary of the Institute.

Manchester and District Branch and Education Group

A joint meeting of the Manchester and District Branch and the Education Group is to be held at the University of Manchester on March 24 at 2.45 p.m. The subject is "Ethical Problems Confronting a Young Scientist in the Atomic Age." Short introductory talks will be given by two young physicists, Mr. H. Burkhardt and Dr. P. Lord and these will be followed by longer contributions from Professor M. Polanyi (University of Manchester) and Professor H. Levy (Imperial College of Science and Technology, London). The Chairman will be Sir Eric James, High Master of Manchester Grammar School. Members may bring guests but admission will be strictly by ticket, obtainable from either the Honorary Secretary of the Manchester Branch or the Deputy Secretary of the Institute.

Non-Destructive Testing Group

The Summer meeting of the Group will be held at the University of Bristol (H. H. Wills Physical Laboratory) from July 11 to 14. The theme of the meeting is "The Physics of Some New Aspects of Non-Destructive Testing." After two introductory contributions, nine papers will be presented and there will be an evening discourse by Professor C. B. Allsopp (*Fellow*) of Guy's Hospital on "Physical Problems of Medical Diagnosis."

Residential accommodation in Wills Hall will be available. The meeting is open to all interested whether members of the Group or not ; a conference fee will be payable by those who are not members of any grade of the Institute. Full details will be circulated to Group members and to any other interested members of the Institute who notify the Group Honorary Secretary.

Forthcoming Institute Meetings

Mar. 14 North Eastern Branch — At Durham Colleges, University of Durham, 6.15 p.m.
"*Modern Infra-red Techniques*"
DR. G. K. T. CONN

Mar. 14 Yorkshire Branch — At the University of Leeds, 7.00 p.m.
Joint Meeting with the Leeds Astronomical Society
"*Radio Stars*"
MR. J. E. BALDWIN

Mar. 21 London and Home Counties Branch — In the William Beveridge Hall, Senate House, University of London, 5.00 p.m.
Joint Symposium
with the Royal Institute of Chemistry (London Section) and the Institute of Biology (London Section)
"*The Presentation of Science to the Public*"
Principal speakers :
DR. A. CLOW (Science Talks, B.B.C.)
MR. J. MCCLOY (Television, B.B.C.)
MR. A. HASLETT (*Penguin Science News*)

Mar. 21 Stress Analysis Group — 12.30 p.m.
Visit to Royal Aircraft Establishment, Farnborough, Hants
(Application to be made to the Deputy Secretary of the Institute)

Mar. 22 Midland Branch — At the University Union, Birmingham, 7.00 p.m.
Branch Annual Dinner
(For details see page 82)

Mar. 24 Education Group and Manchester and District Branch
At the University of Manchester, 2.45 p.m.
"*Ethical Problems Confronting a Young Scientist in the Atomic Age*"
Admission will be by ticket only
(For details see page 82)

Mar. 27 Manchester and District Branch — At the College of Technology, 6.30 p.m.
Branch Annual Dinner
(Details will be circulated to Branch members)

Apr. 5 & 6 Education Group — At the Institute's House.
Annual Group Conference
(For details see page 82)

Apl. 6 Non-Destructive Testing Group 5.45 p.m.

At the Physics Department, Guy's Hospital Medical School, S.E.1.

"*Physical Problems in 'Non-Destructive Testing' in Medicine*"

followed by

demonstrations by the staff of the Department

Apr. 7 London and Home Counties Branch 9.45 a.m.

Visit to the National Institute for Medical Research, Mill Hill

Numbers strictly limited; admission by ticket

(Applications to the Deputy Secretary of the Institute)

Apr. 12 & 13 X-Ray Analysis Group At the Clarendon Laboratory, Oxford.

A joint conference with the Low-Temperature Group of The Physical Society on

"*Low Temperature Crystallography*"

(Programmes and forms of application may be obtained from the Deputy Secretary)

Apl. 13 Liverpool and North Wales Branch In the Electrical Engineering Department, University of Liverpool, 7.00 p.m.

"*The Shear Strength of Monomolecular Layers of a Boundary Lubricant*"

DR. J. S. COURTNEY-PRATT, A.INST.P.

Apl. 13 South Wales Branch University College, Cardiff, 10.30 a.m.

A one-day Conference on

"*Physics in Industry*"

The evening lecture will be given by

SIR JOHN COCKCROFT, K.C.B., C.B.E., F.INST.P., F.R.S.

in the Reardon Smith Lecture Theatre

Admission to the Conference will be by ticket only

(Forms of application may be obtained from the Branch Honorary Secretary)

Apl. 13 Industrial Spectroscopy Group At the Institute's House, 5.30 p.m.

"*Determination of Isotopic Abundance by Emission Spectroscopy*"

MR. F. W. J. GARTON, A.INST.P.

Meetings of the British Nuclear Energy Conference

Constituent Societies :
THE INSTITUTION OF CIVIL ENGINEERS, THE INSTITUTION OF MECHANICAL ENGINEERS, THE INSTITUTION OF ELECTRICAL ENGINEERS, THE INSTITUTE OF PHYSICS AND THE INSTITUTION OF CHEMICAL ENGINEERS

Members of the Institute are invited to attend any of the following meetings arranged by the constituent bodies of the British Nuclear Energy Conference :—

Mar. 20 At The Royal Institution 5.30 p.m.

Sponsored by The Institution of Chemical Engineers

" *The Application of Fluidization Techniques to Nuclear Reactors* "
C. M. NICHOLLS, J. B. MORRIS and F. W. FENNING

Advance copies of the paper will be available on application to the General Secretary, The Institution of Chemical Engineers, 56 Victoria Street, London, S.W.1. Applications for preprints should be accompanied by a stamped addressed label or stamped addressed envelope (9 inches by 6 inches).

Mar. 28 At The Institution of Mechanical Engineers 3.00 p.m.

" *Nuclear Reactors for Power Generation* " ... ... B. L. GOODLET
" *Steam Cycles and Atomic Power Plants* " ... ... R. E. ZOLLER
" *Heat Removal from Nuclear Power Reactors* " PROF. JACK DIAMOND and W. B. HALL
" *Shielding Against Nuclear Radiation* " ... ... C. E. ILIFFE

Accommodation is limited ; applications for tickets should be made to the Secretary of the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, S.W.1 (mentioning membership of the Institute), from whom advance copies of the papers will also be obtainable. Applications should be accompanied by a stamped addressed label or stamped addressed envelope (9 inches by 6 inches).

Apl. 5 At The Institution of Electrical Engineers 5.30 p.m.

" *The Control and Instrumentation of a Nuclear Reactor* " ... A. B. GILLESPIE
" *The Control of Nuclear Reactors* " ... ... R. J. COX and J. WALKER
" *Reactor Control Ionisation Chambers* " ... ... W. ABSON and F. WADE
" *Some Design Aspects of Nuclear Reactor Control Mechanisms* " ... C. E. LOCKETT

Advance copies of the programme will be available on application to the Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Apl. 12 At The Institution of Civil Engineers 5.30 p.m.

" *The Control, Conveyance, Treatment and Disposal of Radioactive Effluents from the Atomic Weapons Research Establishment, Aldermaston* "
W. L. WILSON, P. A. F. WHITE and K. G. MILTON

Advance copies of the paper will be available on application to the Secretary, The Institution of Civil Engineers, 1-7 Great George Street, London, S.W.1.

The Institute's Journals

PRINCIPAL CONTENTS OF THE MARCH, 1956, ISSUES

Journal of Scientific Instruments: Volume 33, No. 3

PAPERS

An attachment for high-temperature single-crystal X-ray work. By L. S. Dent and H. F. W. Taylor (*University of Aberdeen*).

This attachment to an X-ray goniometer permits single-crystal or powder photographs to be taken using copper radiation at up to 900°C. A cylindrical heating element of nickel foil is used, and serves also as a β-filter.

An ultrasonic apparatus for recording the height of water waves in model ship tanks. By E. G. Richardson, F.Inst.P. (*King's College, University of Durham, Newcastle upon Tyne*).

An apparatus is described for measuring the height of water waves on the surface of a model ship towing or manoeuvring tank. The apparatus uses an ultrasonic transducer on the bed. This pulses toward the surface and the echoes returned from successive crests and troughs are recorded continuously on an oscillograph.

Devices for automatic potentiometric titration. By R. Audran (*Kodak-Pathé, S.A., Vincennes, France*), and D. T. R. Dighton A.Inst.P. (*Kodak Ltd., Harrow, Middlesex*).

Two devices capable of automatically performing titrations are described. Both control an electromagnetically operated burette tap from the output of a suitable electrode. The first device, which uses an electronic valve amplifier, is adaptable to any titration the end point of which can be determined potentiometrically. The second, which makes use of a sensitive relay, is only suitable where the electrode used has a low internal resistance.

Some notes on the design and performance of X-ray proportional counters. By A. R. Lang, A.Inst.P. (*Cavendish Laboratory, University of Cambridge*).

For proportional counting of X-ray wavelengths used in diffraction, xenon is the best counter gas, krypton the least suitable. A small, high-efficiency, low-background, xenon-filled counter is described. Argon and xenon counters containing about 10% ethylene operate stably with 50,000-fold multiplication of CuKα ionization, but for undistorted pulse-height distributions at counting rates greater than 10,000 per second multiplication should not be greater than few thousand. Diffraction pattern background intensity of light elements, such as aluminium, is reduced $\frac{1}{4}$ to to $\frac{1}{8}$ of the value as registered by a Geiger counter.

An analysis of injection phenomena in the Birmingham proton synchrotron. By C. A. Ramm, A.Inst.P., R. F. Coe, Grad.Inst.P., and T. B. Vaughan (*University of Birmingham*).

Experimental analysis of the injection processes in the Birmingham proton synchrotron shows that the machine accepts particles for the whole of the theoretical time of injection and that the radio-frequency system accelerates only those particles with very small betatron oscillations. Injection with rising energy gives an increase of more than twice the intensity of the machine output compared with constant energy injection.

A precision high-temperature specimen chamber for an X-ray diffractometer. By G. K. Williamson and A. Moore, Grad.Inst.P. (*University of Birmingham*).

A high-temperature specimen chamber is described in which continuous gas circulation is employed in heating a specimen 1 in. diameter × 0·020 in. thick to a uniform and accurately known temperature. Using techniques sensitive to 0·1°C no temperature differences could be detected between the centre and periphery of the specimen in the range 20–200°C and the difference had a maximum value of less than 1°C at 600°C. In practice the true temperature of the specimen can be measured throughout the range 20–650°C. Temperature fluctuations due to the control circuit never exceeded ±0·5°C as measured on the specimen. The general reliability of the chamber has been critically examined. Slight modification to the instrument should raise the maximum attainable temperature to approximately 900°C.

A continuous-flow rotational viscometer for use with downward-settling suspensions. By G. F. Eveson and E. W. Hall, Grad.Inst.P. (*University of Birmingham*).

A rotational viscometer is described capable of measuring the apparent viscosity of downward-settling suspensions of particles sized below 100 B.S. mesh, where the settling velocity of the particles relative to the dispersion medium is less than 0·2 cm/s.

A simple fast-recycling cloud chamber. By J. Walker, F.Inst.P., G. Tagliaferri, J. C. Bower, F.Inst.P., and D. W. Hadley (*University of Birmingham*).

A simple modification to a standard 9 in. diameter expansion chamber is described which decreases the operating cycle from 60 s to 10 s. Over-compression is used and the results obtained for different operating conditions throw some light on the mechanism of the process.

A simple theory for solid-backed bolometers. By L. M. Roberts and S. J. Fray (*Radar Research Establishment, Great Malvern*).

A simple theory is proposed to explain the frequency response of solid-backed bolometers. It assumes a one-dimensional flow of heat through the bolometer and takes into account the diffusivity of the adhesive used for sticking the bolometer element to its base. The theory has been applied to measurements on some niobium nitride superconducting bolometers and the results are in good agreement with the known properties of the materials used.

A personal γ-radiation monitor with audible warning device. By D. Allenden and I. W. Collip (*Research Laboratory, Associated Electrical Industries, Ltd.*).

A prototype personal γ-radiation monitor is described, which uses an electrometer valve and transistor alarm circuit to give an audible warning to the wearer on receipt of a tolerance dose of γ-radiation. The insulation requirements of the valve and chamber circuits and the design of the alarm circuits are discussed, particular attention being paid to ease of checking and "fail-safe" features. It is concluded that the desired performance is consistently realizable in the design presented, a dosage accuracy of the order of $\pm 5\%$ being achieved.

LABORATORY AND WORKSHOP NOTES

Large liquid-filled plastic lenses.
By J. W. Telford *and* N. S. Thorndike.

Measurement of the damping of metal bar specimens in mechanical resonance.
By H. Pursey *and* E. C. Pyatt.

A simple method of controlling the temperature of a prism.
By K. P. Norris.

CORRESPONDENCE

Correction of millimetre mercury barometers.
From D. Ambrose *and* P. H. Bigg.

A liquid scintillator containing nitrogen.
From J. R. Prescott.

NEW INSTRUMENTS, MATERIAL AND TOOLS.

British Journal of Applied Physics: Volume 7, No. 3

SPECIAL ARTICLE

Rain—natural and artificial. By R. C. Sutcliffe, O.B.E. (*Meteorological Office, London, W.C.2*).

Mean precipitation over the earth's surface is about 90 cm per year. This is balanced by evaporation using about 20% of the total solar energy incident upon the earth and its atmosphere. The world patterns of precipitation and evaporation do not coincide; balance is maintained by transport in wind systems. The mechanisms for condensing the vapour require vertical motion and adiabatic cooling by expansion: by orographic ascent, vertical (static) instability and large-scale cyclonic (dynamical) instability. Supersaturation does not occur owing to the presence of minute nuclei in vast numbers. Cloud droplets have diameters of about 10μ and number about 200/cm^3. Raindrops have diameters about 1 mm equivalent to about 10^6 cloud droplets. The process of combination may be by coalescence of droplets (warm rain) or by distillation from water droplets on to ice crystals at sub-freezing temperatures. The introduction of nuclei or ice crystals (silver iodide, common salt, solid carbon dioxide, etc.) into cloud may produce a little precipitation in special circumstances but no method of economic value is yet established. Interference with radiation, evaporation or the large-scale dynamics is conceivable but at present purely speculative.

Summarized proceedings of a conference on electron microscopy—Glasgow, July, 1955.

The Annual Conference of the Electron Microscopy Group of The Institute of Physics was held in the Department of Chemistry, University of Glasgow, from July 5 to 7, 1955. The papers presented are summarized in this report.

Papers

Origin and analysis of gas in electron tubes.

By S. J. Stoll, Diamond Ordnance Fuse Laboratories, Washington, D.C., U.S.A.

It is shown that the gas liberated in an electron tube, during electron bombardment of the anode, originates in the oxide-coated cathode. This gas was found, by spectrographic analysis, to be nearly all carbon monoxide. The significance and relative effects of tube processing on tube gas are shown.

Diffusion (or conduction) along a slightly tapering tube, and its application to the determination of diffusion coefficients.

By A. Talbot and J. A. Kitchener (*Imperial College of Science and Technology, London, S.W.*7).

The diffusion equation has been solved for the case of diffusion from a slightly tapering tube into an infinite medium of zero concentration. The theory provides a means of correcting results obtained for diffusion coefficients in the capillary tube method of Anderson and Saddington, when the tube is not of uniform bore throughout its length. This is frequently the case when silica capillary tubes have to be used (as for high-melting substances) and the correction is often significant.

The wall effect and the viscometry of suspensions.

By A. D. Maude and R. L. Whitmore, A.Inst.P. (*Dept. of Mining and Fuels, University of Nottingham*).

When the viscosity of a suspension of spherical particles uniformly distributed in a simple liquid is measured in a capillary tube viscometer, a wall effect, which is not found with coaxial rotating cylinder viscometers, is observed. The paper suggests that it may be caused by a redistribution of a portion of the suspension particles on entering the tube of the viscometer, leading to a reduction in both the concentration and viscosity of the suspension near to the walls of the tube. The diminution in concentration is measured experimentally and found to yield a value for the wall effect which is in agreement with that obtained from viscosity measurements. The reason for the redistribution of the particles at the tube inlet is discussed.

Coplanar mesh storage.

By G. R. Hoffman, Electrical Engineering Department, University of Manchester.

The paper describes a cathode-ray tube capable of storing an array of binary digits on a special target surface. The target surface incorporates a mesh which is sensibly coplanar with the storage surface and, therefore, simple to manufacture by evaporation. An attempt was made to develop a storage system that would combine the advantages of mesh storage with the simplicity of control of the Williams-Kilburn system in two steps, namely, transfer of control to the bright-up mechanism and the elimination of transient voltages on the mesh. The store for comparable spot size has a greater packing density than the normal non-mesh cathode-ray tube store, and at low speed operation the output signal is controllable both in amplitude and sign. The limits of the output signal amplitude are discussed and methods of improving the speed of operation and output amplitude are described.

Correspondence

The determination of base thickness in alloy junction transistors by etching.
From J. Rolfe.

Current distribution in an expanding spark channel.
From J. M. Somerville *and* C. T. Grainger.

Decomposition of $CaSO_4 . 2H_2O$ in the electron microscope.
From J. H. Talbot.

A replica technique for " reflexion " electron microscopy.
From L. Holland.

The square wave response method of analysing process control systems.
From E. Persson ; L. Mandel.

Ferrites in resonant cavities.
From R. A. Waldron.